NATIONAL AIR INTELLIGENCE CENTER
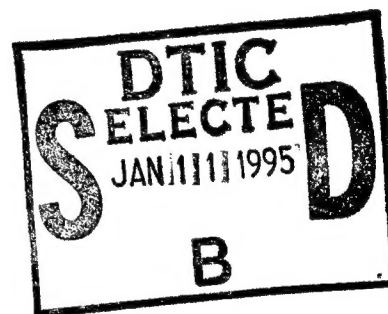
INFLUENCES OF FILM STRUCTURES ON LASER DAMAGE THRESHOLDS

by

Wu Zhouling, Fan Zhengxiu

DTIC
SELECTED
JAN 11 1995

B

19950109 128

HUMAN TRANSLATION

NAIC-ID(RS)T-0639-93   15 December 1994

microfiche # 94C000562

INFLUENCES OF FILM STRUCTURES ON LASER DAMAGE THRESHOLDS

By: Wu Zhouling, Fan Zhengxiu

English pages: 9

Source: Guangxue Xuebao, Vol. 9, Nr. 9, September 1989;
          pp. 830-834

Country of origin: China
Translated by: SCITRAN
                F33657-84-D-0165
Quality Control: Nancy L. Burns
Requester: NAIC/TATD/Bruce Armstrong
Approved for public release; Distribution unlimited.

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

ORGANIZATION	MICROFICHE
B085 DIA/RTS-2FI	1
C509 BALL0C509 BALLISTIC RES LAB	1
C510 R&T LABS/AVEADCOM	1
C513 ARRADCOM	1
C535 AVRADCOM/TSARCOM	1
C539 TRASANA	1
Q592 FSTC	4
Q619 MSIC REDSTONE	1
Q008 NTIC	1
Q043 AFMIC-IS	1
E051 HQ USAF/INET	1
E404 AEDC/DOF	1
E408 AFWL	1
E410 AFDTC/IN	1
E429 SD/IND	1
P005 DOE/ISA/DDI	1
P050 CIA/OCR/ADD/SD	2
1051 AFIT/LDE	1
PO90 NSA/CDB	1
2206 FSL	1

Microfiche Nbr: FTD94C000562

NAIC-ID(RS)T-639-93

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged int
translation were extracted from the best quality copy av

STOP HERE

1

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

ORGANIZATION	MICROFICHE
B085 DIA/RTS-2FI	1
C509 BALL0C509 BALLISTIC RES LAB	1
C510 R&T LABS/AVEADCOM	1
C513 ARRADCOM	1
C535 AVRADCOM/TSARCOM	1
C539 TRASANA	1
Q592 FSTC	4
Q619 MSIC REDSTONE	1
Q008 NTIC	1
Q043 AFMIC-IS	1
E051 HQ USAF/INET	1
E404 AEDC/DOF	1
E408 AFWL	1
E410 AFDTC/IN	1
E429 SD/IND	1
P005 DOE/ISA/DDI	1
P050 CIA/OCR/ADD/SD	2
1051 AFIT/LDE	1
P090 NSA/CDB	1
2206 FSL	1

This article takes TiO_2/SiO_2 and ZrO_2/SiO_2 film systems as examples and studies the influences of different film structures such as $A(HL)^m HG$, $A[(2p+1)HL]^m (2p+1)HG$, as well as $A[H(2q+1)L]^m$, and so on, on laser damage threshold values. At the same time, it combines studies on measurements of optical losses and the effects of protective film thicknesses, making a preliminary probe into laser damage mechanisms as associated with optical thin films.

Key Terms: Optical Thin Films; Laser Damage; Optical Losses

I. FORWARD

Laser damage associated with thin films is the result of mutual effects between lasers and thin films. It involves the two aspects of the lasers and the thin films. A precise knowledge of the empirical rules associated with these two aspects is advantageous for setting forth the mechanisms of laser damage associated with thin films and elevating laser damage threshold values associated with film layers[1,2].

This article takes TiO_2/SiO_2 and ZrO_2/SiO_2 multiple layer media reflective films as an example and studies the influences on laser damage threshold values of different film system structures, such as, $A(HL)^m HG$, $A[(2p+1)HL]^m (2p+1)HG$, as well as $A[H(2q+1)L]^m HG$. It was discovered that, following along with increases in the thicknesses of high refractive index media layers, optical film system laser damage threshold values monotonically drop. However, following along with increases in the thicknesses of media layers with low refractive indices, the laser damage threshold values first obtain, monotonically, improvements of relatively great amplitude. Following that,

when $(2q+1) \geq 7$, the relevent film system laser damage threshold values abruptly drop far below the standard film system $A(HL)^m HG$.

On the basis of results from preliminary experiments on thickness effects, measurements of optical losses were combined and a preliminary probe was done into the mechanisms of laser losses associated with optical thin films.

II. EXPERIMENTS

1. Sample Preparation: All samples were evaporated and plated onto a K_9 glass base. The film system designs, technical manufacturing conditions, and film material refractive indices were as shown in Table 1.

2. Experimental Methods: Laser damage experimental equipment was as shown in Fig.1. Experimental data are set out in Table 2. Damage tests selected for use the 1-on-1 method, that is, on the surface of samples, one laser irradiation only was done on the same location, no matter whether or not this location was destroyed. The damage status associated with samples was determined by the observations of a high power microscope placed at the back. Damage threshold values were defined according to traditional threshold values. The formula representing them is[3]:

$$F_{th} = \frac{[E_{max}(ND) + E_{min}(D)]/2}{A},$$

In the equation, $E_{max}(ND)$ is the highest energy at which samples do not sustain damage. $E_{min}(D)$ is the lowest

2

energy at which samples sustain damage. A is the area of
irradiation faculae on the surface of samples.

Table 1 Coating design deposition parameters and refractive indices of the samples investigated ($\lambda=1.06\ \mu m$)

No.	Material	design		deposition parameters	n
		$(p,\ q)$	$A[(2p+1)H(2q+1)L]^3(2p+1)HG$		
1	HiTiO$_2$ LiSiO$_2$	(0, 0)	$A(HL)^3HG$	EB evaporation $T_s=200°C$	$n_H=2.40$ $n_L=1.46$
2		(1, 0)	$A(3HL)^33HG$		
3		(2, 0)	$A(5HL)^35HG$	$T_{baking}=400°C$	
4		(0, 1)	$A(H3L)^3HG$		
5		(0, 2)	$A(H5L)^3HG$		
6		(1, 3)	$A(H7L)^3HG$		
7	HiZrO$_2$ LiSiO$_2$	(0, 0)	$A(HL)^3HG$		$n_H=1.90$ $n_L=1.46$
8		(1, 0)	$A(3HL)^33HG$	EB evaporation	
9		(2, 0)	$A(5HL)^35HG$	$T_s=200°C$	
10		(0, 1)	$A(H3L)^3HG$	$T_{baking}=200°C$	
11		(0, 2)	$A(H5L)^3HG$		
12		(0, 3)	$A(H7L)^3HG$		

Table 2 Experimental parameters of thr damage testing

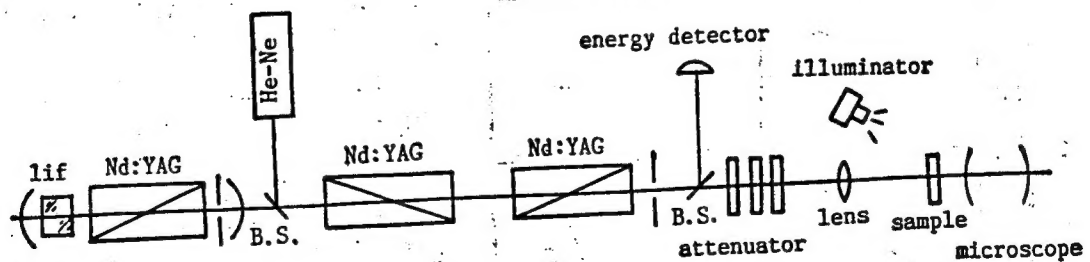| wavelength	$1.06\ \mu m$
mode	TEM$_{00}$
pulse width (FWHM)	10 ns
spotsize $1/e^2$	$44\ \mu m$

Fig. 1 Experimental Setup for damage testing

The choice was made to use pulse photothermal deviation
techniques to measure the absorption[4,5] of experimental

film or coating systems. The test equipment was a colinear type of arrangement, that is, pump light (Nd:YAG, λ =1.06 μ m) and probe light run parallel to each other and approach colinearity[6]. This is as shown in Fig.2. This type of method to measure light absorption associated with multi-layer media films or coatings is sensitive to A 10^{-5}. Its repetition accuracy is better than 10%. The film or coating system overall integral scattering measurments were carried out on a laser thin film scattering measurment device test manufactured by the institute in question. This instrument takes He-Ne lasers as the measurment light sources. It opts for the use of optical modulation weak signal synchronous locked phase techniques. Sensitivity reaches 10^{-5}. Relative measurment errors are better than 15%[7,8].

III.   RESULTS AND DISCUSSION

The results of measurment tests on laser damage threshold values for thin film samples which were measured as well as for optical losses were as shown in Table 3. If one takes these results and represents them in the form of curves, then, they are as shown in Fig.3. From Table 3 and Fig.3, it is possible to see that:

1. Laser damage threshold values clearly depend on the structure of film or coating systems. The general laws are: Following along with increases in the thicknesses of high refraction index media layers, laser damage threshold values monotonically decrease. However, following along with increases in the thickness of media layers with low refraction indices, the laser damage threshold values first monotonically obtain improvements of a relatively large amplitude. After that, when $(2q+1) \gtrsim 7$, the laser damage

threshold values associated with film or coating systems abruptly drop far below the damage threshold values associated with the standard $A(HG)^3HG$ film or coating system.
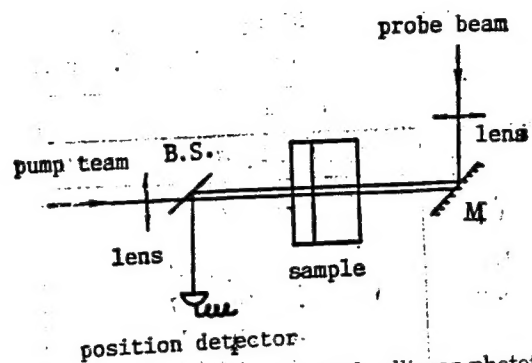

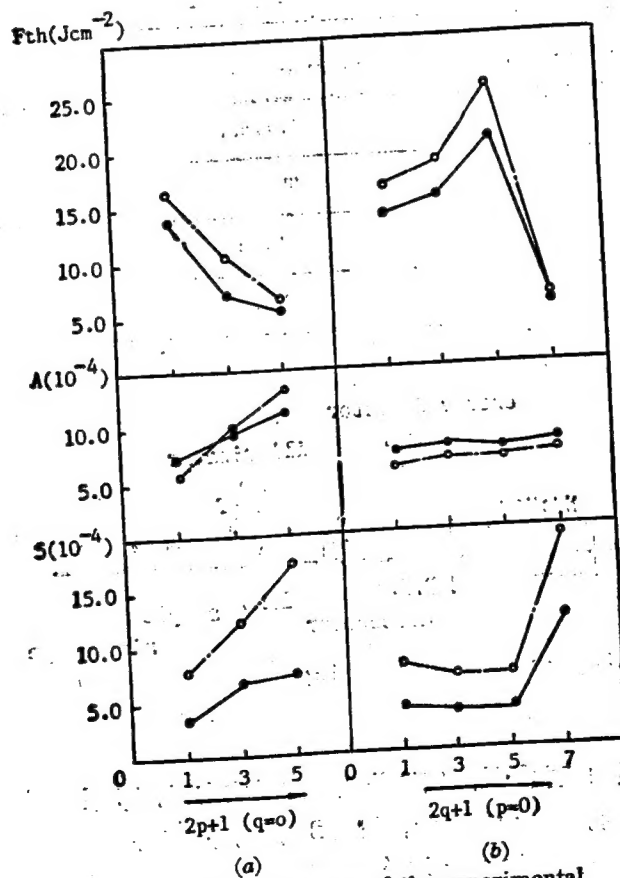Fig. 2 Schematic illustration of pulsed collinear photothermal deflection technique

Fig. 3 Representation of the experimental results in table 3

○—TiO_2/SiO_2; ●—ZrO_2/SiO_2

2.　Absorption and scattering losses also have a
relatively strong dependency relationship with film or
coating system structures.　The general laws are:　Following
along with increases in the thicknesses of media layers with
high refractive indices, sample absorption and scattering
both monotonically increase.　However, following along with
increases in the thickness of media layers with low indices
of refraction, on one hand, sample absorption is basically
unchanged.　On the other hand, sample scattering first shows
a slight drop.　After that, it rises very quickly and
abruptly.　This forms a comparison for the abrupt drop in
damage threshold values discussed before.

　　An analysis of the experimental results discussed above
makes it possbile to reach a number of preliminary
conclusions.

　　1.　System absorption and system scattering associated
with media layers having high indices of refraction make key
contributions to overall absorption and overall scattering
in film or coating systems.

Table 3　Measured damage thresholds and optical losses of the samples investigated

date ＼ sample	S_1	S_2	S_3	S_4	S_5	S_6
F_{th}(J cm^{-2})	13.8±1.8	7.0±1.6	5.1±1.2	15.2±1.8	20.3±2.0	6.0±3.2
A(10^{-4})	7.1±0.5	9.5±0.8	11.2±1.0	7.6±0.7	7.4±0.6	7.8±0.7
S(10^{-4})	3.28±0.27	6.58±0.72	7.3±0.81	3.15±0.22	3.01±0.21	10.4±4.3
date ＼ sample	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
F_{th}(J cm^{-2})	16.2±1.9	10.3±3.1	6.4±2.8	18.4±1.6	25.1±1.8	5.8±3.3
A(10^{-4})	5.6±0.6	9.8±1.2	13.2±1.8	6.2±0.6	6.4±0.8	6.9±0.7
S(10^{-4})	7.83±0.25	12.1±0.31	17.3±2.8	6.65±0.19	6.70±0.20	19.2±3.4

2.   Optical film or coating system laser damage
threshold values follow along with increases in the
thickness of media layers with high indices of refraction
and monotonically drop. The causes can be understood like
this. Increases in the thickness of media layers with high
indices of refraction lead to increases in absorption. Cross
section structures associated with films or coating media
with high indices of refraction are normally generated in
the form of cylinders or columns. Following along with
increases in the thickness of film or coating layers, the
cylinder form structures get coarser and coarser, and pits
or holes become more and more numerous[9].

3.   Optical film or coating system laser damage
threshold values follow along with increases in the
thickness of media layers with low indices of refraction and
achieve improvements of relatively great amplitude. This
phenomenon is capable of being understood as the SiO_2 film
or coating's low refraction index materials and the cross
section structures associated with the majority of thin
films or coatings being different from each other. This is
generated by particle states. The structures are
meticulously uniform[9]. Because of this, in multiple
layer media film or coating systems, SiO_2 has improving
effects on boundary structures. This type of improvement
effect increases along with increases in film or coating
thickness. When $2q+1=5$, it reaches the optimum. At this
time, if one advances the increases still further in layer
thicknesses of media with low indices of refraction, by
contrast, due to stress effects, within multiple layer media
films or coatings, a good number of extremely small
striations are formed. This causes film or coating system
scattering to obviously increase, and damage threshold
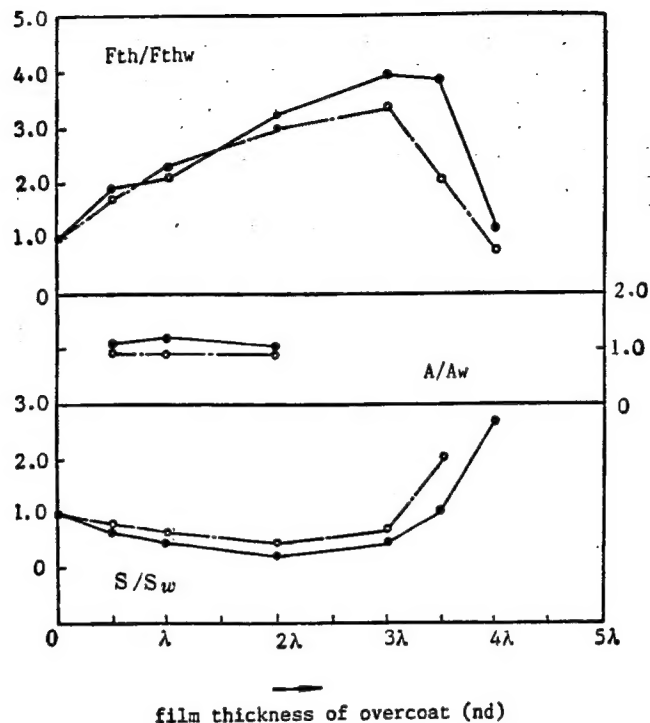values drop a large amount.

834

7

Fig. 4 Film thickness effect of SiO_2 overcoats:
○—TiO_2/SiO_2 HR; ●—ZrO_2/SiO_2 HR.
(Index w indicates measured results of the samples without overcoat)

This article also studied thickness effects associated with highly reflective membranes and protective membranes or films. The relevent experimental results are as shown in Fig.4. Comparing Fig.4 and Fig.3(b), it is not difficult to see that the two possess unusually similar patterns or regularities. This phenomenon is explained by the fact that highly reflective membranes or films possess protective effects associated with protective films or coatings and have similar mechanisms to increases in film or coating system damage thresholds from low refractive index film layers in multiple layer media films or coatings. Low refractive index SiO_2 films improve micro-structures associated with high refractive index media layers adjacent to them.

8

IV. CONCLUDING REMARKS

This article studied the influences of film or coating systems on multiple layer media reflective film optical losses and laser damage threshold values. In conjunction with this, it combined experimental results associated with film thickness effects on higly reflective film protective membranes or coatings. It made prelimiary probes into relevent mechanisms and arrived at a number of preliminary conclusions. These conclusions have a definite instructive meaning for the design and manufacture of strong laser thin films. Measurements and tests on damage threshold values associated with film or coating systems are also capable of supplying references to personnel concerned.

REFERENCES

[1] C. K. Carniglai; *SPIE*, 1986, **692**, 202.

[2] K. H. Guenther; *SPIE*. 1987, **801**, 200.

[3] K. H. Guenther *et al.*; *Appl. Opt.*, 1984, **23**, No. 21 (Nov), 3743.

[4] D. L. Balageas; *J. Appl.Phys.*, 1986, **59**, No. 2 (Feb), 348.

[5] W. B. Jackson *et al.*; *Appl. Opt.*, 1981, **20**, No. 8 (Apr), 1333.

(6) Wu Zhouling; "China Laser" 21989,16,No.8(Aug), 468

(7) Chen Yisheng, et al; "China Laser" 1985,12,No.3(Mar) 183.

[8] Y. S. Chen *et al.*; *ICO*-13 *Conference Digest*, (Sappore, Japan 1984), **546**.

(9) Fan Zhengxiu, "Laser Magazine" 1982,9,No.9(Sep),582.